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Model-based Governance: A Cybernetic Approach to Water Allocation Control

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Abstract

Just like calcium, magnesium, and iron, water is vital for life on our planet. Alarming evidence indicates that water is becoming scarce. In this critical situation, the management of hydric systems turns out to be a bottleneck. Established modes focus on regulation through laws and rulings. This paper offers a methodological contribution to improving the governance of River Basin Organizations (RBOs): a cybernetic model is introduced for the diagnosis and (re-)design of water governance, which is new in this context: the Viable System Model (VSM). This model embodies both a theory and a methodology, incorporating a heuristic cybernetic framework. The theory it provides is unique in its claim to specify the necessary and sufficient preconditions for the viability of any social system. It gives access to the deep structures that ensure the viability of social, and thereby socio-ecological and socio-technical systems. The VSM also provides a methodology that is highly beneficial in environmental, social, and economic terms. Using the VSM in the field of water governance is unorthodox and challenging. It has the potential to balance the need and supply of water, and even to reframe the system-in-focus, ensuring its viability and sustainability. The theoretical claim of the model is underpinned by an extensive case study from the Tocantins-Araguaia Hydrographic Region in Brazil—the largest hydrographic basin completely within Brazil. The insights gained from this account allow for cautious generalization and enable impactful applications.

Keywords Organizational cybernetics · Viable system model (VSM) · Variety engineering · Complex adaptive systems · River basin organizations (RBOs) · Integrated water resources management (IWRM)

Introduction

The availability of water resources is among the most pressing challenges facing humanity today. Water scarcity has reached critical levels in many regions, exacerbated by rising demand, pollution, climate change, and poor management practices. These challenges threaten the viability of social and ecological systems, underscoring the urgent need for effective governance of hydric systems.

Over the past decades, the discourse on water scarcity has gained substantial prominence, especially in light of severe droughts across the Southern Hemisphere and beyond (Suleymanov 2024; Santarosa et al. 2022; Cicilinski and Virgens Filho 2020; UNESCO 2020; Vieira 2020; Mostert 2017, Schulze and Schmeier 2012). While considerable research has addressed technical and ecological solutions to water-related issues (Darwish et al., 2021; Rauch et al. 2021; Javaid and Falk 2015), less attention has been paid to the organizational structures and governance frameworks needed to ensure the viability and sustainability of hydric systems (Rojas et al. 2024; Pahl-Wostl et al. 2023; Kittikhoun and Schmeier 2021; Ison and Wei 2017; Ison et al. 2013). Furthermore, the water sector continues to rely predominantly on centralized and hierarchical management approaches, which often fail to address the complexity and multidimensionality of hydric systems (Pahl-Wostl et al. 2020, 2021; Harwood 2018).

This highlights a significant gap in the current governance models, as the existing frameworks are ill-equipped to manage hydric systems in the face of climate change and growing demands. Integrated Water Resources Management (IWRM), understood in this work as an "Integrative System of Water Governance" that aligns institutional regulations, political leadership, and systemic coordination, is a comprehensive framework with the potential to promote the coordinated development and management of water, land, and related resources, maximizing economic and social welfare equitably without compromising the sustainability of ecosystems. As part of this framework, River Basin Organizations (RBOs) are frequently advocated as a best practice for sustainable river basin management, despite limited evidence regarding their

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effectiveness in managing complex hydric systems (Bouckaert et al. 2018).

However, as these institutional frameworks continue to evolve, their ability to address the interdependencies and dynamic interactions inherent in river basin governance remains a critical question. To address this issue, we introduce a new approach for dealing with that question: the Viable System Model (VSM), a cybernetic framework developed by Stafford Beer (1981, 1985), which provides a unique lens for diagnosing and (re-)designing organizational structures and processes. While the VSM has been applied in various domains, including enterprises, cities, and regions, with great success, its application to RBOs is a novel contribution. Hence, we pose the following research question: What can a cybernetic perspective teach us about the organization and governance of RBOs and their possible improvements for achieving viability?

This article seeks to bridge the methodological gap in water governance research by applying the VSM to the case study of the Tocantins-Araguaia Hydrographic Region in Northern Brazil. By focusing on this region as a *pars pro toto* - representing broader governance and management[2] challenges - the study offers actionable insights into diagnosing structural issues and (re-)designing integrative governance solutions for RBOs.

The paper first outlines the challenges of governing RBOs, then presents the research methodology and the case study findings. Moreover, it discusses the implications for redesigning water governance, concluding with recommendations for fostering the viability of these systems.

Unveiling the Governance challenges in river basin organizations

According to Bouckaert et al. (2018), an RBO aims to govern a basin's geographic boundaries using a bioregional approach that allows a system-wide perspective, combined with a coordination function across the often-numerous subcatchment organizations that can exist within a river basin or even as part of a water transfer scheme.

These organizations also seek to tackle complex governance challenges by fostering stakeholder collaboration, ensuring transparency, and recognizing interdependencies at the river basin scale. In this way, some RBOs can exhibit strong elements of polycentric governance in practice (Gerlak et al. 2021; Huitema et al. 2009; Schlager & Blomquist 2008).

Globally, RBOs vary widely in their tasks, responsibilities, and institutional arrangements, reflecting a "patchwork" of models influenced by regional and historical contexts (Jaspers and Gupta 2014). Supported by international organizations, countries such as the U.S., Australia, and France have served as reference points for the development and institutionalization of RBOs worldwide.

Despite their potential, RBOs are often criticized for institutional shortcomings, such as inefficiencies, overlapping responsibilities, and high transaction costs, which can hinder effective governance (OECD 2015a). Additionally, RBOs are perceived by some stakeholders as resource-intensive structures that fail to meet expectations, potentially discrediting the broader water governance system (OECD 2015b).

According to regime theory, RBOs operate as institutions that provide institutionalized principles, norms, and mechanisms around which actors' expectations converge (Kittikhoun & Schmeier 2021). While their explicit political objectives are often understated, RBOs contribute significantly to political stability by facilitating communication and cooperation, particularly during times of tension or conflict. Their governance mechanisms, which include data-sharing platforms, dispute resolution forums, and stakeholder involvement processes, underline their capacity to support integrative water management (Schmeier 2013).

However, the Brazilian context presents unique challenges for RBOs. While they are recognized as key components of water governance, their complex and sometimes overlapping structures create inefficiencies and gaps in governance systems. The implementation of policies for water allocation, especially those with detailed criteria for inter- and intra-sectoral distribution, remains the exception rather than the rule (OECD 2015a). Recent developments, such as formal water regulatory agreements and water allocation agreements, have sought to address these issues, but they have largely been reactive responses to emerging problems.

Ensuring viability in river basin organization

Addressing water governance issues requires a comprehensive examination of the organizational frameworks used by RBOs and their ability to adapt to the evolving dynamics of basin-level decision-making. We decided to rely on the Viable System Model (VSM) as a methodological framework for our study. The VSM, which will be presented in detail shortly, embodies a theory that we have selected because of its outstanding features: it is the only theory

[2] The working definition we use conceives of governance as the system of rules, practices, and processes by which an organisation is directed and controlled (Chen 2025). The concept of management is conceived as the design, control, and development of organisations (Ulrich 2001). We use the two terms by and large synonymously.

Table 1 The Viable System Model subsystems and their functions

Sub-System 0 (S0):	Basic Operative Unit ("basic unit"), accomplishing the purpose of the overall system
Sub-System 1 (S1):	Local Management ("regulatory capacity") of a basic unit. We call a basic operative unit with its regulatory capacity a "primary unit"
Sub-System 2 (S2):	Coordination of these primary units, attenuation of oscillations between them
Sub-System 3 (S3):	Executive Management of a collection of primary units
Sub-System (S3*):	Auditing and Monitoring channel
Sub-System 4 (S4):	Intelligence, i.e., management for the long term, relationships with the overall environment
Sub-System 5 (S5):	System Identity and Ethos/Normative Management

addressing a highly generic and comprehensive systems objective — the viability[3] of organizations — while claiming to establish the necessary and sufficient structural preconditions for such viability.

This claim has profound implications: a social system is viable if, and only if, its structure meets a set of requirements specified by the theory. "Necessary conditions" refer to basic elements without which an organization cannot function, such as formal structures or clearly articulated functions and responsibilities. However, these elements alone do not guarantee viability. "Sufficient conditions" go further, they ensure that the organization is capable of adapting and surviving in a complex and changing environment. As Beer (1981, p.132) noted, organisational theories generally do not state sufficient conditions for viability; they often fail even to distinguish between necessary and sufficient conditions.

According to the VSM, a viable organization must contain a set of managerial subsystems and their interrelationships, as defined by the theory (Beer, op. cit.); see Table 1.

Any deficit in the structure, such as missing functions, insufficient capacity of the functions, or faulty interaction between them, will inevitably impair the viability of the organization. This structure is recursive: to be viable, not only the system-in-focus (e.g., a River Basin) but also its subsystems (e.g., Catchments) and supersystems (e.g., a set of River Basins) must be structured according to the same principles. This is known as the principle of recursion. Recursive organization applies only to those units fulfilling the organization's purpose, not merely regulatory or supporting functions.

The VSM, therefore, offers more than a checklist of organizational components; it provides an integrative framework that articulates how these components should interact to support viability in practice.

Methodology

The Viable System Model (VSM) has been widely applied across a range of organizational contexts. A review of the relevant literature reveals two primary categories of contributions. First, several authors have documented applications of the model for diagnosing and (re)designing systems. For instance, Beer (1970, 1989) applied the VSM to national economic management in Chile; Espejo and Harnden (1989) and Schwaninger (2005) explored organizational viability in public and private sectors; Hoverstadt (2008) analyzed corporate structures; and Espinosa (2023) applied the model to local governments and community-based systems. Alves et al. (2020) examined its application to fisheries policy governance in Brazil, while Gomez et al. (2019) applied it to educational systems in Colombia.

Second, a substantial body of work has contributed methodologically to how the model is used. The foundational writings of Beer (1979, 1981, 1984, 1985) remain central for understanding the recursive structure of organizations and the differentiation between operational and metasystemic functions. Clemson (1984) offered practical guidance to applying the model; Espejo and Reyes (2011) and Espinosa and Walker (2011) developed participatory diagnostic tools; Pérez Ríos (2012) proposed structured modeling frameworks; and Lassl (2019a, 2019b, 2019c) emphasized iterative model development through organizational interaction. Pfiffner (2022), focuses primarily on private-sector applications, drawing connections between neurobiological insights and organizational governance.

We propose applying the Viable System Model (VSM) (Beer 1979, 1981, 1984, 1985) as a cybernetic framework for diagnosing and (re-) designing water governance structures within RBOs. This approach aims to ensure coordination both vertically across different levels of government and horizontally across policy sectors. Horizontal coordination emerges through negotiated autonomy and real-time feedback among operational units, whereas

[3] It is worth noting that viability and sustainability are nearly synonymous (Espinosa 2023). Viability refers to the ability to continue existing or developing as a living system. Sustainability, on the other hand, is defined as the quality of causing little or no harm to the environment, thereby enabling continued existence over the long term (Cambridge Dictionary). Organizing for sustainability, therefore, implies organizing for viability (Schwaninger 2018:1226).

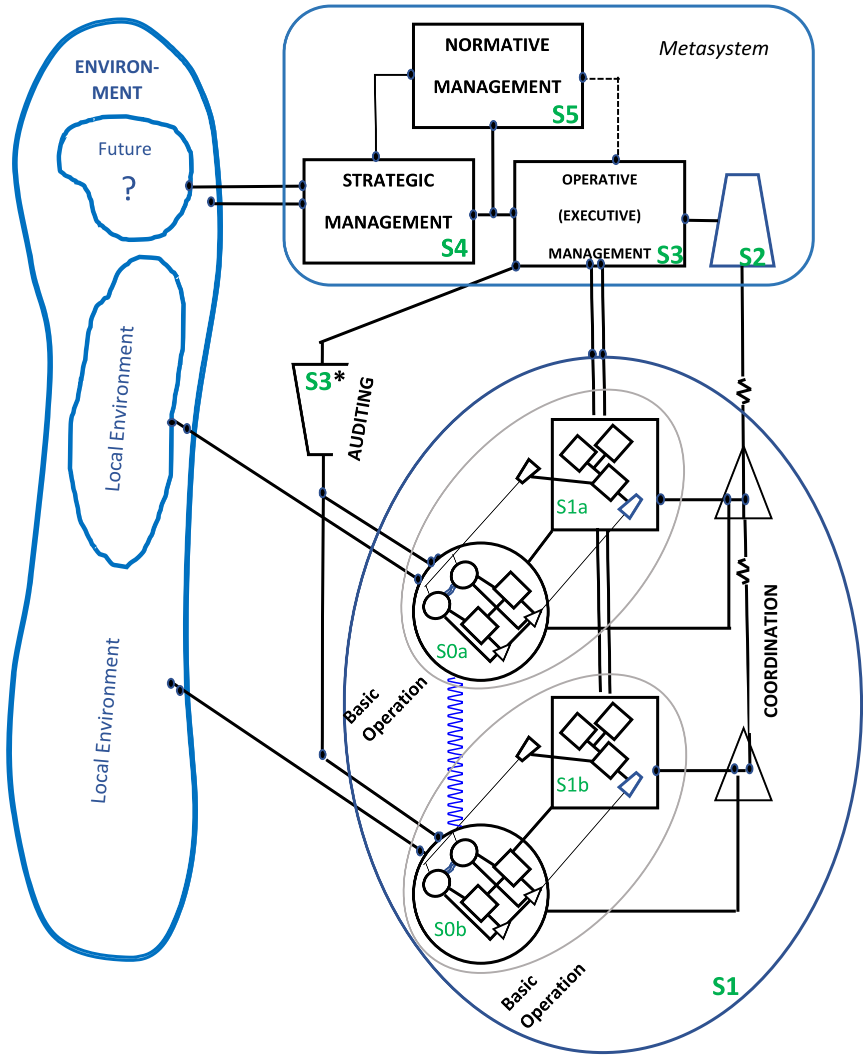

Fig. 1 Viable System Model (VSM). Source: Schwaninger (2009), after Beer (1985)

vertical coordination is maintained through regulatory and strategic oversight from the metasystem. Together, these elements enable cohesion, adaptability, and viability across all levels of organizational recursion, see Fig. 1.

To explore this framework in depth, a single-case design is employed. Under a well-defined set of circumstances, single-case designs are an appropriate research strategy. Yin (2015) outlines the criteria for selecting such cases, including critical cases for testing well-formulated theories, extreme or unique cases, representative or critical cases, revelatory cases, and longitudinal cases.

The case analyzed here fulfills several of these criteria. First, it is a critical case, as it examines a real-world application of a novel model with high potential. The researchers involved possess a unique, proven level of expertise in both the subject matter and the research methodology. Essential prerequisites, such as access to the research object and its stakeholders and the availability of documentation, were ideal. Second, the case is revelatory because it applies a new governance system, shedding light on aspects not addressed by conventional organizational theories. Third, the case is longitudinal, as critical parameters are analyzed in terms of their long-term evolution.

The data for this research were collected from multiple sources. Following Yin's protocol (2015), we used multiple sources of evidence, including documentation, archival records, interviews, direct observations, participant observations, and maps.

For the case study, documents corroborated the theory and enhanced the evidence obtained throughout all phases of the research process. Systematic searches for documentation were conducted within the National and State Water Resources Information System (SNIRH) between January 2019 and August 2024. A database was created to organize this information by dates, categories, and areas.

Primary data collection occurred during several phases of fieldwork, including stakeholder interviews and workshops. Structured interviews involved 64 individuals representing

Table 2 Overview of the conducted fieldwork

Fieldwork phase	Activity
Aug–Febr 2021	Partially structured interviews: interviews were conducted with representatives from the public sector, organized civil society, users, and experts. Over 64 individuals were interviewed, encompassing the three categories outlined in the composition of the State Water Resources Management System (SEGRH).
Aug–Sep 2021	Survey: A questionnaire was specifically designed for administration to members of the State Council of Water Resources (CERH) and the Formoso River Basin Committee (CBHRF), also known as the 'Water Parliament'. The instrument consists of 20 questions, distributed across 9 different categories inspired by the meta-questions of the Viable System Model (VSM). Out of the 33 CERH members (S5), 30.3% responded to the questionnaire, and out of the 31 CBHRF representatives (S3), 25.8% responded.
Nov/2020–Nov/2024	Direct and participant observation: Direct and participant observations posed a significant challenge for this research and provided unique opportunities for data collection in the case study. Direct and participant observations primarily took place during regular and extraordinary meetings of both the State Council of Water Resources (CERH) and the Formoso River Basin Committee (CBHRF) from November 2020 to November 2024. Participation in the North Region Workshop for the review of the National Water Resources Plan (2022–2040) on 5th May 2021 also provided an opportunity for interaction among CERH and CBHRF members within the context of ongoing institutional reforms.
Mar/2022–Aug/2024	Validation: Efforts of consensus validation and expert validation were undertaken. In line with the case study protocols, the research findings were presented to the president and members during a regular meeting of the CBHRF in August 2022. The diagnostic section particularly captured their interest, and the group expressed clear agreement with the model-based diagnosis and design proposal, representing consensual validation. For the participating experts, this served as expert validation. Additionally, the research was presented in July 2022 to the State Secretary of Environment and Water Resources (Semarh), who also presides over the State Council of Water Resources (CERH). She concurred with the diagnosis, which was her primary focus of interest.

two large stakeholder groups. The details are provided in Table 2.

This is not a hypothesis-testing research project; therefore, statistical tests are not part of the study. However, during feedback sessions with stakeholders, both consensus validation and expert validation[4] were conducted (for more details, see Alves 2022).

The system-in-focus: Formoso River Basin Organization

The Tocantins-Araguaia Hydrographic Region pursues a purpose, which is typical for large hydric systems: Its raison d'être is to ensure the provision of water that is quantitatively sufficient and qualitatively adequate for production and consumption within its catchment area, balancing demand and supply.

The potential for system viability is contained at each level of recursion, i.e., each RBO at any level of recursion pursues its own viability. The structure displayed in Fig. 2 maintains primary units at all recursive levels in balance, at least within the limits set by a higher-order unit. This means that the autonomy of these units is high but limited by the need for cohesion among all primary units. In VSM terms, a regulatory system and the hydric system it controls are referred to as a primary unit. This recursive framing allows for the analysis of how viability is maintained — or threatened — within and across different organizational layers, a central concern in complex water governance systems.

Each of the primary units identified in the hydric system – insofar as it fulfills its purpose – is a structural replication of the whole in which it is embedded. These units are designed to ensure water services of regulation, provision, and support, in addition to cultural services related to water. The formation of recursive units is not based on political or administrative criteria, but follows the geography of ecological and social systems.

We selected the Formoso River Basin Organization (Formoso RBO) as our unit of analysis, representing a level of recursion below the Javaés RBO. The choice of the Formoso RBO is theoretically motivated: it provides a situated context in which the principles of the Viable System Model (VSM) can be applied and reflected upon. This governance configuration is marked by institutional complexity, environmental stress, and asymmetric power relations — all of which shape and are shaped by the perceptions and actions of those involved. In line with second-order cybernetics, this perspective recognizes the observer as part of the system, highlighting the

[4] Consensus validation refers to a process in which multiple stakeholders or participants reach agreement on the relevance or adequacy of findings or models, typically through discussion and negotiation. In our case, this took place in two workshops attended by all stakeholders, a total of about 40 people. Expert validation, on the other hand, involves evaluation by individuals with recognized expertise in the subject matter, who assess the quality, accuracy, or applicability of the results based on their specialized knowledge. Expert validation was a matter of work sessions in the research team, and in bilateral conversations with specialists in water policy and its associated management instruments.

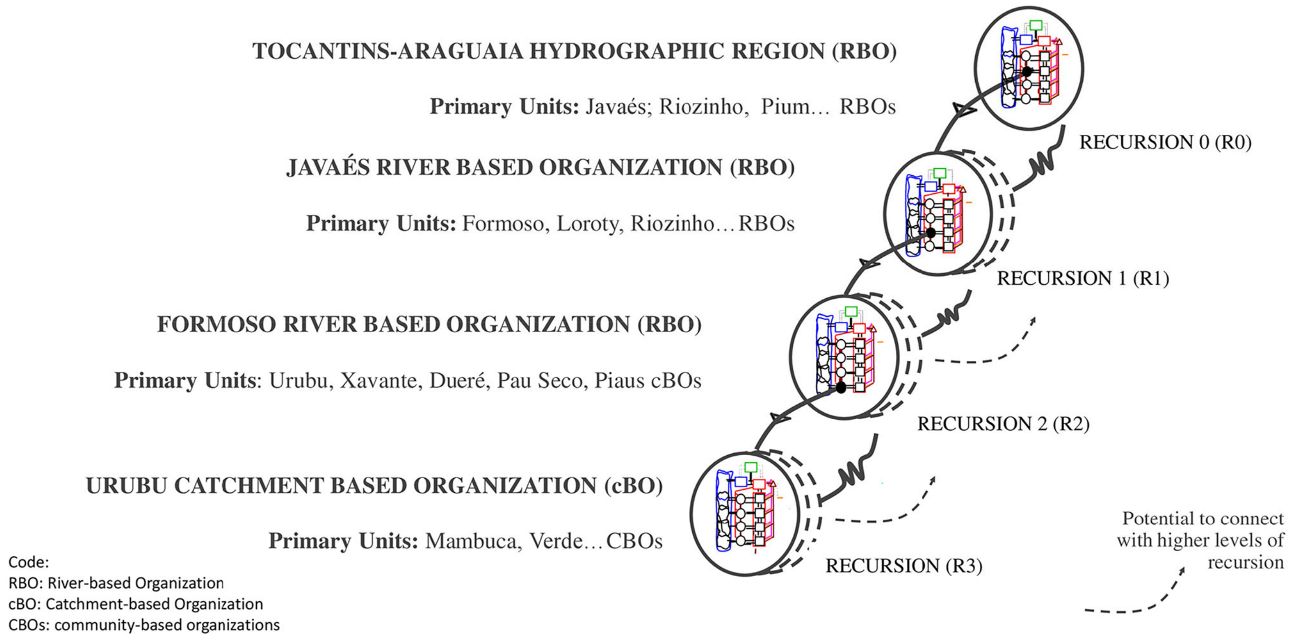

Fig. 2 Recursive levels of the primary units. Source: Adapted and modified from Schwaninger (2018)

interpretative and participatory nature of diagnosing the viability of a complex dynamic system.

Located in the southwest region of the state of Tocantins, the Formoso River Basin consists of five main catchments: Piaus, Pau Seco, Xavante, Dueré, and Urubu (see Fig. 3).

The Formoso RBO supports one of the world's largest continuous areas of irrigated rice, supplying water to major agricultural enterprises. Official data on water consumption for irrigation is imprecise. However, the Formoso RBO records an annual consumption of nearly 600 billion liters of water across 100,000 hectares of irrigated area (ANA 2021a). This region lies within the direct impact area of the Araguaia National Park (PNA), a strict protection conservation unit recognized as a UNESCO Biosphere Reserve and a wetland of international significance under the Ramsar Convention – the 'intergovernmental treaty for the conservation and wise use of wetlands and their resources'.

Water allocation in the Formoso RBO has long been critical due to recurring water scarcity. In 2016, water rights permits were suspended for 120 days (Naturatins 2016). Even earlier, the 2011 State Water Resources Plan (PERH) reported that irrigation demand accounted for 96.5% of water use, about 26 m^3/s, highlighting ongoing pressure on resources (Tocantins 2011). In response to persistent overexploitation and ineffective regulatory enforcement, the Public Prosecutor's Office of the State of Tocantins (MPE-TO) filed a *Ação Cautelar* No. 001070-72.2016.827.2715, which was upheld by the judiciary. This judicial intervention reinforces the perception of a system under institutional strain, unable to self-correct without external legal measures.

It is evident that the Formoso RBO requires appropriate mechanisms for coping with such complex issues. The irrigation systems represent a problem of asymmetry in resource access, privileging some users, which amplifies the challenges associated with provision and extraction. Therefore, management and allocation of water in the Formoso RBO are closely linked, as the most efficient allocation regimes require greater coordination among the various stakeholders, and a strengthening of the capacity to respond to institutional innovations proposed for IWRM.

In this regard, Ashby's (1956) assertion is invoked that any control system must strive for requisite variety, i.e., a repertoire of behaviors ('variety'[5]) that is equivalent to the repertoire of the system it is controlling; otherwise, a complexity gap and imbalance will arise.

Diagnosis of Water Governance: What Works and What Does Not?

We will now analyze the systemic architecture of the Formoso River Based Organization (Formoso RBO). The

[5] 'Variety' is a concept by which the term 'complexity' can be concretized, for example measured. It denotes the number of states or modes of behavior a system can assume (potentially) or assumes (actually). 'Variety' is also used as a synonym for 'repertoire of behavior' or for 'complexity'. See Ashby (1956) and Schwaninger (2009).

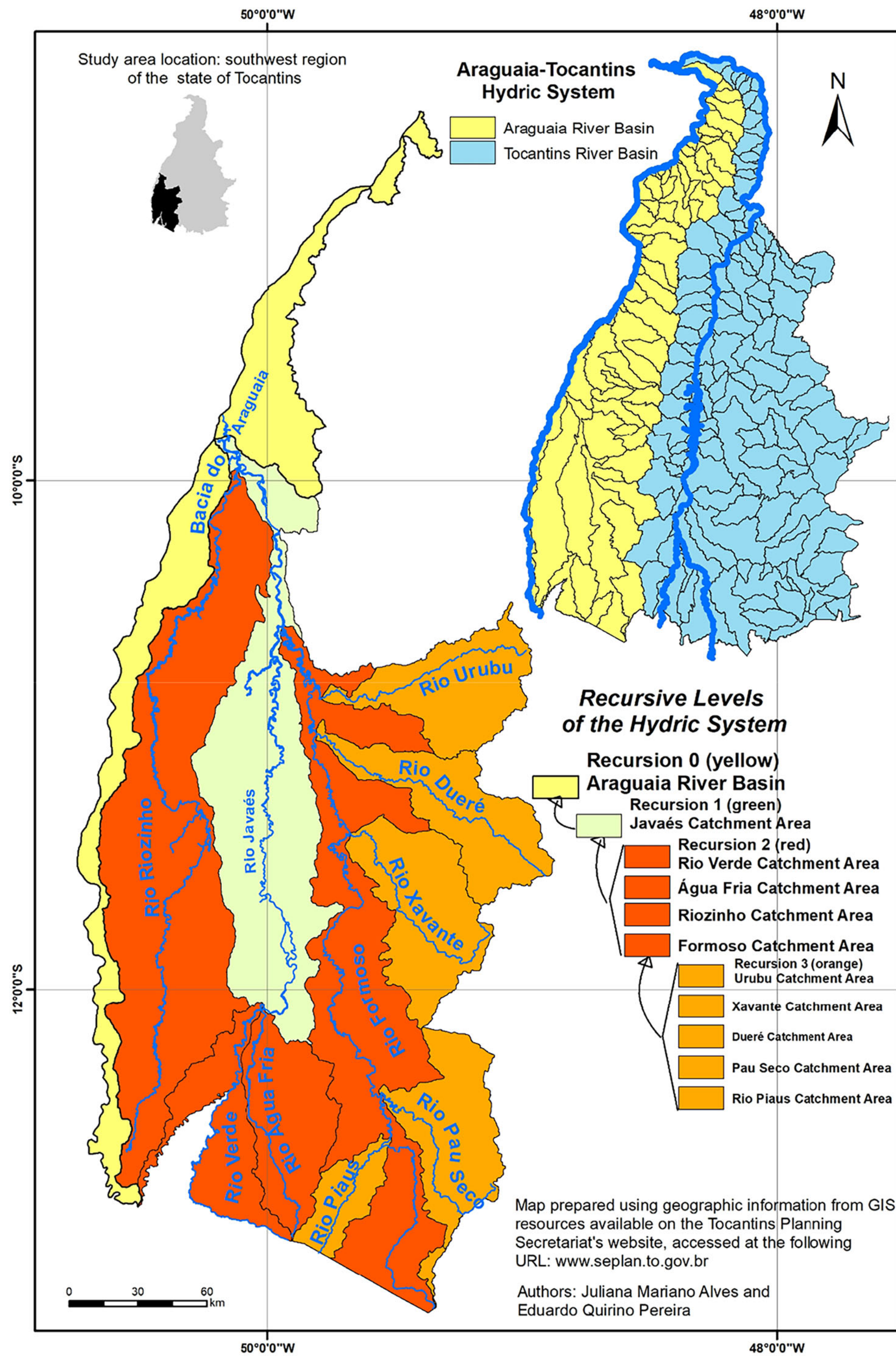

Fig. 3 Recursive levels maps of the primary units

resulting mapping, shown in Fig. 4, provides an overview of the current state of water governance. Key dysfunctions are highlighted in red.

The diagram illustrates the constellation of organizational stakeholders involved in the scope of IWRM within the Formoso RBO, along with the functions of the five subsystems (S1 … S5) of the Viable System Model (VSM). Additionally, the connections between these subsystems, such as S1 ↔ S3, S3 ↔ S4, etc., are depicted.

This diagram serves as an organizational diagnosis, which we will discuss in the following sections. The various institutions mentioned in the description are defined in a glossary, see Appendix A.

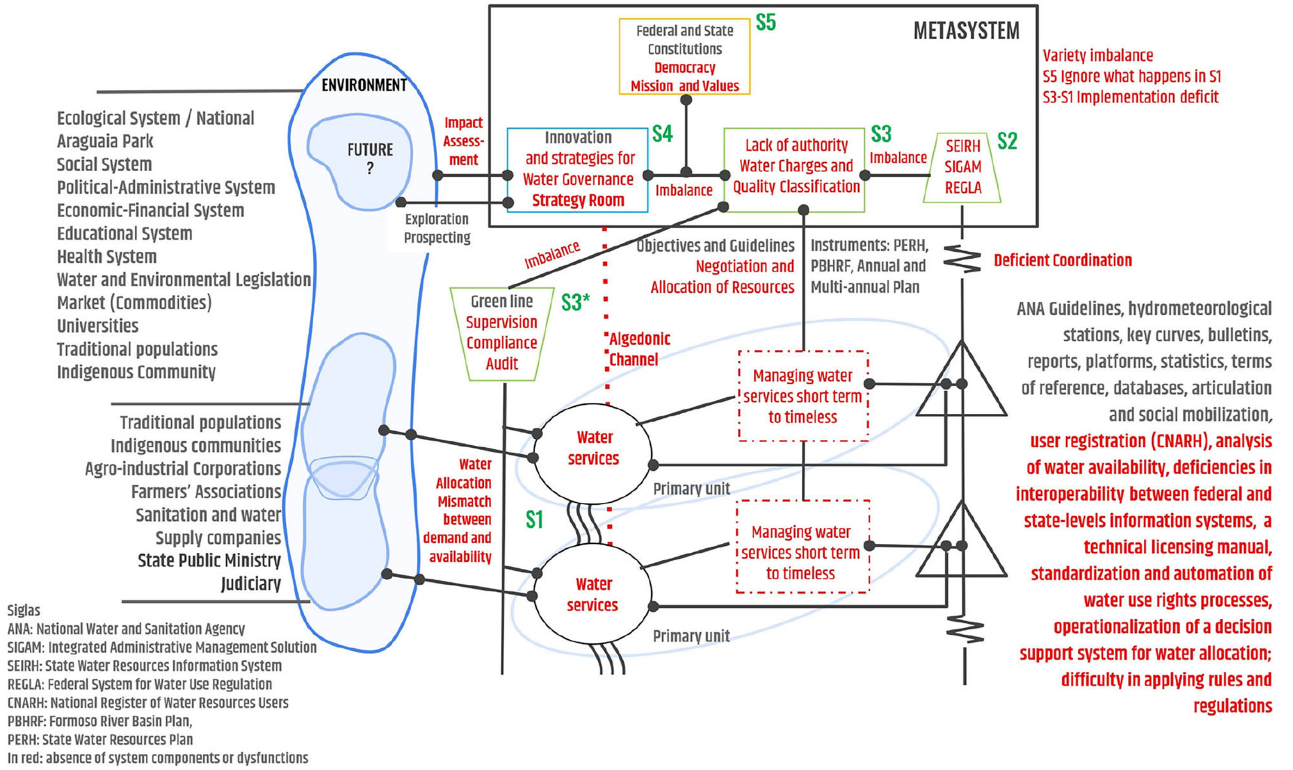

Fig. 4 Diagnosis of the Formoso River Based Organization - Level R2

The primary units and their relationship with the environment (S0-S1↔ Environment)

Analyzing the interrelations and different levels of recursion within the system under study, we observed significant transformations in the environment over the past decades. The growing demand for water, coupled with climate-related changes in the water cycle, is increasingly posing non-trivial challenges for managers, particularly in balancing water availability with intensive use related to the expanding commodity market.

The expansion of irrigated areas has raised demand beyond the catchments' capacity, depleting available resources and gradually causing water scarcity. The demand for irrigation water is primarily concentrated in the middle and lower course of the Formoso RBO. Records indicate that in the region encompassing the primary units related to the Urubu, Dueré, Xavante, Ribeirão Lago Verde catchments, and marginal areas to the Formoso River, the demand exceeded by 186.7% the allocable flow in the months of July and August (Tocantins 2007). Additionally, Xavante, Escuro, and Pau Seco catchments have municipal headquarters with a critical alert level concerning water production and supply systems, as per the Water Security Index (ISH-U) (ANA 2021b).

The capacity for water governance in the Formoso RBO is directly linked to the ability to deal with the multiplicity of factors affecting the water services and water service management. However, the Water Law No. 9.433/1997 (Brasil 1997) and shifts in management had introduced substantial complexity to the management of the Formoso RBO. The water permits, along with water charges, river basin plans, water quality standards and water information systems were formally described in the law as water management instruments.

The integration and coordination of these instruments, remain a challenge, as the evolving legal and managerial frameworks continue to test the system's capacity to adapt and effectively balance the competing demands on water resources. In the catchments areas of Formoso RBO, overly optimistic estimates of available water resources and subsequent over-allocation of water rights permits have led to severe shortages during drought periods.

A deficit in S1 was identified, resulting from the absence of a functioning River Basin Agency (AgB), which would be responsible for local management and the implementation of normative and strategic measures established at higher levels of governance. This absence compromises the system's ability to manage its operational variety, leaving a structural gap in the execution of core functions. As a result, the metasystems of the primary units become fundamentally deficient, not due to a lack of formal structures per se, but because the missing S1 functions undermine the cohesion, coordination, and regulation expected at higher systemic levels. In this vacuum, dominant stakeholder groups—such as agroindustrial corporations, farmers' associations, and even the judiciary—step in to fill the gap, but do so in ways that often reflect asymmetrical interests rather than systemic viability.

This means that S1 is strongly affected by the decision-making of the environment and specific contexts for managing the purposeful activities in Formoso RBO. In practice, this compromises the governance, since decision-making must be handled by the Formoso River Basin Committee (CBHRF), based on the Formoso River Basin Plan (PBHRF).

The basic units behave like 'autopoietic beasts'[6], where the focus is solely on individual objectives, without a clear sense of how their actions fit into the purpose of the system in focus. This means that subunits tend to self-manage and maintain its own functional identity (autopoiesis), often at the expense of cohesion and the overall effectiveness of the larger system. The lack of an integrated vision leads to conflicts, duplication of efforts, and environmental degradation, as the actions of one unit may negatively impact others.

Coordination (S2)

In this section, we examine how data availability, institutional interoperability, and digital infrastructure impact the coordinative function (S2) in the Formoso RBO, and how these systemic weaknesses contributed to judicial intervention in 2016. The coordinative function within water management is essential for effective leadership. This function operates not through a rigid hierarchy but rather through dynamic communication and information exchange, which helps to smooth out oscillations among primary units involved in IWRM.

Brazil relies heavily on integrated information systems that facilitate data sharing and enhance decision-making processes. A key initiative in this landscape is the National Register of Water Resources Users (CNARH), created to identify users of both surface and groundwater. While this register primarily supports operational monitoring (S3*), it also contributes to coordination (S2) by enabling broader visibility over water use patterns. In 2014, the National Water and Basic Sanitation Agency (ANA) launched the CNARH-40 platform to integrate data related to regulated water uses across federal and state jurisdictions.

However, in Tocantins state, the lack of seamless integration between federal and state systems means that much of the data must be manually processed and transferred. This restriction results in inefficiencies, reduces transparency, and compromises responsiveness. These challenges are particularly acute in the Formoso RBO. For instance, official records report 6,547,403 m^3/year for human supply and an implausible 1,378,509,368 m^3/year for irrigation (Tocantins 2015). This figure is not only disproportionate when compared to regional water availability and crop demand but also exceeds the physical capacity of the irrigation infrastructure in place at the time. Such a volume suggests either cumulative errors in data entry, multiple overlapping grants, or a lack of updated monitoring of actual water use.

Our analysis revealed recurring inconsistencies in water use permits. In 2013, for example, only one grant for human supply was registered in the municipality of Aliança do Tocantins, despite other municipalities depending on water from the Formoso RBO. More critically, we identified permits authorizing flows up to 20 times higher than those allowed by Decree 2432/2005, which sets limits based on 75% of the minimum flow with 90% permanence[7].

The situation escalated to the extent that, in response to *Ação Cautelar* No. 001070-72.2016.827.2715, filed by the State Public Prosecutor's Office in 2016, the Court of Justice of the State of Tocantins issued a ruling in 2023 mandating twenty-seven corrective measures, several of which have a direct impact on the coordinative function (S2). Among the key directives were the expansion of the hydrometeorological network, automation of permit and allocation processes, and improvement of real-time data access.

To address these issues, Nature Institute of Tocantins (Naturatins), the state environmental agency responsible for implementing water policy instruments such as the granting of water use rights, recently signed an agreement with National Water and Basic Sanitation Agency (ANA) to enhance its water usage grants system and improve integration between the Integrated Environmental Management System (SIGAM) and the Federal Usage Regulation System (REGLA). This agreement aims to adopt the Decision Support System for Water Allocation (SSDO), which will

[6] The term 'autopoiesis', derived from Greek, means 'self-creation' or 'self-production' and refers to systems that have the capacity to self-organise and self-maintain through their own interactions and internal processes. The term 'autopoietic beasts' refers to entities or systems that self-organize and sustain themselves but carries a more critical connotation. Here, the term 'beast' can be understood as a metaphor to describe systems or behaviors that, despite their autonomy and capacity for self-reproduction, may operate in a dysfunctional or predatory manner.

[7] The criterion of 75% of the minimum flow with 90% permanence refers to a regulatory standard established to ensure sustainable water usage. Specifically, it indicates that the authorized flow rate for water use should not exceed 75% of the minimum flow level, which is determined based on historical data, and that this flow rate should be maintained 90% of the time over a specified period. This approach aims to protect aquatic ecosystems and ensure the availability of water resources during dry periods.

streamline the process of granting water usage rights. In any case, interoperability issues among SIGAM and REGLA information systems and a lack of technical capacity to interpret and utilize available data further exacerbate challenges related to granting water use rights in the Formoso RBO.

The State Department of Environment and Water Resources (Semarh) has been working on expanding the hydrometeorological network and ensuring the consistency of historical data. Currently, the network comprises 60 Data Collection Platforms (PCDs) in regular operation. However, the primary challenge for expanding the number of platforms lies in increasing the number of field personnel to maintain these PCDs and ensure they operate effectively with reliable, real-time data.

The current distribution of PCDs remains insufficient, resulting in information silos and inconsistent data within local regulatory centers of primary units. This fragmentation hinders coordination among governance levels. The lack of a comprehensive system for collecting and sharing water data obstructs the identification of trends and swift responses to issues like water scarcity and pollution. Therefore, implementing strategies to enhance the data collection network and improve communication among regulatory agencies is crucial for the State Water Resource Information System (SEIRH).

Executive Management (S3)

The S3 embodies the short-to-mid-term perspective of the system-in-focus (‘here and now’). It manifests itself through the legal authority to deliberate on water management at the river basin level, which is vested in the Formoso River Basin Committee (CBHRF). According to ANA (2022a), this is known as the ‘Power of the State,’ signifying the authority of CBHRF to make decisions regarding a public good that must be enforced.

Operating on the principle of integrative, participatory, and decentralized management, the CBHRF is composed of representatives from government agencies (including federal, state and municipal public-sector members), water users, and organized civil society. These public-sector representatives, while not formally “governors,” play a role in translating state policies into basin-level implementation and are directly involved in deliberations. The committee is expected to implement technical tools, negotiate conflict resolution, and ensure water security within democratic institutions. Its structural design aims to coordinate joint and organized action among all stakeholders involved.

However, the CBHRF has assumed institutional responsibilities but lacks the resources to implement and monitor the Formoso River Basin Plan (PBHRF). The PBHRF provided a diagnosis and prognosis of water demand and availability in the Formoso RBO, already highlighting issues of incompatibility between demand and water availability since 2007.

The CBHRF fails to regulate the organization’s resource stocks to ensure its stability over time. It does not adequately establish responsibilities and accountability within the organization, nor does it effectively define the boundaries between S1, their relationship with the entire organization, and the principles by which they should operate. This is evident in the statement made by one of its members in the interviews: ‘*The CBHRF lacks financial autonomy to fulfill its constitutional role*.’

Our participant observations in the CBHRF meetings reveal that the primary concern of users often revolves around monitoring the evolution of the committee’s decisions, which could impact their rights or incur costs (e.g., changes in allocation regimes and water charges), rather than actively seeking solutions to the issues within the Formoso RBO.

The effectiveness of the CBHRF is compromised by low representativeness[8] and lack of continuity, largely due to the impacts of political cycles on public sector members[9], which result in frequent turnover and limited institutional memory among newcomers. This lies at the heart of the governance challenges related to the CBHRF.

The CBHRF is responsible for proposing the classification of water quality, as well as charging for water use. Therefore, without the information generated by primary units, it lacks the strength to generate cohesion or extract the necessary synergies for implementing the tools. The deficiency in S1 (lack of AgB) weakens the capacity of S3, with its competencies, knowledge, and resources often overshadowed by the influence of dominant groups.

A clear example of this is the establishment of fee rates in 2015—set at R$ 0.015 per cubic meter for water abstraction and R$ 0.160 per cubic meter for sewage discharge. These rates were formally approved by the CBHRF and the State Council of Water Resources (CERH) through Resolution No. 056/2015, which holds the competence to set such values. However, for these rates to have legal force and be effectively implemented, they must be formalized through a state government decree.

Although Decree No. 6604 (Tocantins 2023), intended to regulate water charging, was only approved by the government of Tocantins in 2023, critical details, such as the start date of charging and the authority responsible for

[8] Which refers to the limited participation of various water users, within the stakeholders represented in the CBHRF, the agricultural sector holds predominant influence.

[9] The state of Tocantins has had seven governors, but four of these terms were not completed. Political instability in the state has been marked by resignations and impeachments, particularly following allegations of electoral fraud.

collection, remain undefined. Even now, in July 2025, the charging system has yet to be implemented.

The CBHRF lacks the capacity to support primary units if they encounter challenges, such as formulating regulations that define water use norms, licensing criteria, contingency plans, and water quality standards. The regulations are formulated by the CBHRF, which defines these rules based on the operational and standardization guidelines established by System 2 (S2), aiming to ensure coordination and stability across units. Additionally, the rules align with the strategic and normative principles set by the CERH, which, as the representation of System 5, safeguards the system's identity, cohesion, and legitimacy. All of these rulings must align with the priorities of ecosystem conservation and sustainable water use, the objectives of increasing water efficiency and protecting water quality, and the available financial, human, and technological resources outlined in the PBHRF.

Auditing and monitoring (S3*)

In the VSM, the sporadic nature of system 3* is necessary to capture the unpredictable and spontaneous side of an organization that heavily relies on planning and regulation. In our system-in-focus, S3* is manifested through the role of monitoring and auditing activities, exercised by Naturatins, an entity of indirect public administration, which employs its power of administrative policing to ensure compliance with the current regulatory acts.

In the Formoso RBO, two significant challenges arise concerning monitoring and auditing. First, Naturatins struggles to fulfill its responsibilities as outlined in the PBHRF. This is largely due to its extensive duties, which include supervising all aspects of environmental licensing across the state of Tocantins. The burden of multiple responsibilities hampers its effectiveness, limiting Naturatins' capacity to maintain rigorous supervision.

Second, there is a concerning lack of compliance among permit holders with the terms of their licenses. This situation reflects a broader absence of a culture of rule compliance within the region. It is vital to raise awareness among users regarding the reasons behind the institutional regulations mandated by IWRM. Users must grasp the risks associated with non-compliance, as well as understand collective benefits that can arise from proactive engagement and compliance.

To address these challenges regarding the implementation of and compliance with water use permits, active citizen participation in the monitoring of water consumption is essential. Encouraging users to report deviations through the Naturatins hotline can help foster a culture of accountability. Anyone can report environmental crimes in Tocantins simply by contacting Naturatins' Green Line and providing the requested information.

Despite evident challenges in water allocation especially during times of shortage, Naturatins currently lacks the necessary capacity to effectively monitor and audit water allocation practices due to low staffing levels and insufficient infrastructure to implement necessary actions. Additionally, the lack of hydrometeorological measurement stations limits the information flow within the water management information systems, further diminishing the effectiveness of its supervisory functions.

The channels S1 ↔ S2 ↔ S3 ↔ S3*

Having examined the horizontal relationships of the primary units - that is, their connection with the environment - as well as the lack of vertical linkage between the regulatory capacities of S1 and S3, the structural deficits of S2 and S3* as support for primary unit management, we will now delve into the connections where operations play a role.

For any regulatory subsystem of the VSM to function, it concretely requires information from the primary units of the system-in-focus. However, the observed mismatch between demand and water availability results from incomplete, inadequate, or delayed information emanating from primary units. The communication channels of S2 connecting to S1 and S3 are not yet sufficiently developed for S2 to efficiently fulfil its coordination functions.

In our system-in-focus, the operational metasystem (S2, S3 and S3*) is too small to cope with the challenges of managing and coordinating the S1. The infrastructure is insufficient, and the technical team is limited. The communication channels between S1<->S2<->S3<–>S3* still lack the operational variety required to process, for instance:

- Inconsistencies in historical data from hydrometeorological monitoring stations;
- Lack of automation within decision support systems for water allocation;
- Insufficient training capacity;
- Low capacity for supervision and compliance auditing in the primary units;
- As well as a lack of provision of the technical licensing manual to guide water users.

There are still many uncertainties regarding the institutional capacity of the communication channels between S1 < - > S2 < - > S3 ‹-› S3* to transmit the information from the variety amplification mechanisms required for the granting of water allocation. According to Perez Ríos (2012), the fragmentation of information systems, their manifestation as information islands, or the lack of continuous and uninterrupted infrastructures linking them, will leave the organisation without a fundamental element for its proper functioning.

Strategy and organization development (S4)

S4 embodies the long-term perspective of the Formoso RBO. The fundamental role of S4 is to monitor what happens or may happen in the organization's environment, capturing relevant information and channeling it to enhance institutional intelligence. It is the organ that moderates the participative process of strategizing and leads the design of strategies.

The S4 of the system-in-focus demonstrates institutional capacity to recognize and consolidate trends. Tocantins is a signatory to the National Pact for Water Management, an initiative of the ANA in partnership with the states of the Brazilian Federation.

The Tocantins State Department of Environment and Water Resources (Semarh) plays a crucial role in implementing the Pact's strategies. Through a financial incentive program from the ANA, known as Progestão, Semarh promotes coordination among various levels of government and civil society. It also contributes to the development and implementation of water resource management policies and plans at the state level.

The goals of Progestão are divided into two categories: federative cooperation targets, defined by ANA based on legal regulations or information sharing, and water resource management targets at the state level. These state-level targets are selected by Semarh and approved by the State Water Resource Council (CERH). The aim is to promote shared governance, based on clear and measurable targets, while focusing on voluntary adherence and strengthening local water management capacities.

The state of Tocantins joined Progestão through State Decree No. 4.915/2013, beginning to fulfill the goals of the first cycle in 2014 and is now in the final phase of the third cycle. The state of Tocantins is classified under typology B, requiring a satisfactory qualitative-quantitative balance in most basins, with concentrated uses in a few basins facing qualitative-quantitative criticality (critical areas).

The report from the last cycle emphasizes the need for greater participation of the CERH in the water governance process (ANA 2022b). In our participative observations, it is noted that the plans and accountability reports presented by Semarh are often validated by the CERH without a comprehensive discussion of the underlying strategies. This lack of critical debate limits the effectiveness of the decisions made.

Active participation from the CERH is essential not only to ensure transparency but also to foster a collaborative environment that encourages the exchange of ideas and the joint construction of solutions. The absence of deeper dialogue can result in plans that do not reflect local realities and needs, hindering adaptation to the specificities of Formoso RBO.

Otherwise, Semarh faces challenges such as excessive bureaucracy in the acquisition of goods and contracting of services, as well as the need for effective strategies for integrating management systems to guarantee the reliability of real-time data and the proper functioning of the Strategy Room (ANA 2022b).

The Strategy Room was established using financial resources from the ANA. Developed within the framework of the Water Law No. 9.433/1997 (Brasil 1997), these rooms are designed to integrate hydrological data, meteorological forecasts, and reservoir operations to inform decision-making in real time. In successful cases, such as in the São Francisco and Paraíba do Sul RBOs, Strategy Rooms have operated as dynamic spaces that connect technical analysis with institutional response, especially during critical events like droughts or floods. Their effectiveness depends not only on infrastructure and data availability, but also on institutional articulation, clear protocols, and active participation from committees and councils. When properly integrated into management routines, these rooms reinforce adaptive capacity, strengthen the link between information and action, and embody the systemic principles of decentralized and participatory governance outlined in the Water Law No. 9.433/1997 (Brasil, op. cit.).

Despite its potential, the Strategy Room has been underutilized in Tocantins state, limiting its effectiveness as a central hub for real-time data analysis and decision-making. To maximize its capabilities, it is essential to enhance the engagement of CBHRF and CERH and integrate the Strategy Room into regular management procedures.

The channel S3 ↔ S4

Strategy-making requires the collaboration between CBHRF and Semarh, in a continual discourse about the long term. Such a discourse is missing. Semarh faces difficulties in proposing appropriate strategies for the Formoso RBO.

Although the Semarh website has been providing specific information about the composition of the CBHRF, including entities, members, mandates, addresses, capacity status, and other relevant details, in line with ANA's standards, it is crucial to carefully consider the evaluation of the goals established in Progestão.

Despite Semarh's strong position in the evaluations, it is important to note that the process is self-evaluative. Evaluating the impacts of Semarh's strategies involves analyzing the consequences of its policies, regulations, and initiatives related to water resource management and environmental protection. The absence of requisite variety suggests that our S4 may lack the necessary tools or capabilities for comprehensive and effective impact analysis, limiting its ability to learn and adapt.

On the other hand, it is the function of CBHRF to inform Semarh about the status of the primary units – strengths, weaknesses, threats, and opportunities. However, as we have seen, CBHRF lacks sufficiently developed communication channels with primary units and coordination to amplify its operational variety and fulfill the functions determined in the IWRM framework.

Normative Management - Organizational Identity and Ethos (S5)

The S5 constitutes the supreme authority of the organization and, as such, is the only organ with the capacity to regulate the interaction between S3 and S4. It embodies a perspective that is very long-term, if not 'timeless.'

The S5 of the system-in-focus is a public and state body, concentrating on the task of political leadership in IWRM. The State Council of Water Resources (CERH) is the supreme decision-making body of IWRM in the state of Tocantins. The mission, values, and constitutive objectives of the CERH are also known and are deeply rooted in the constitutional principles of Brazilian democracy and sovereignty.

Therefore, in addition to balancing the stability of the organization's intrinsic control[10] and its constant adaptation to the demands of the environment, the CERH has the function of ensuring that the organization maintains its purpose, *vis-à-vis* the sustainability of hydric systems.

However, the CERH's deliberative role often resembles that of a 'registration chamber', meaning it functions primarily as a body that formalizes decisions already made elsewhere, without fostering substantive debate or exerting effective influence over the course of deliberations. From reading the minutes of the meetings, it appears that the water scarcity crisis was not adequately discussed in the CERH between the years 2016 and 2024. The lack of knowledge about the functions and competencies of the CERH as the supreme instance for conflict resolution is recorded in the mentioned documents. Implicit in this is the absence of values, norms, and rules of conduct that must prevail and permeate the organization at all its levels of recursion. Organizational 'ethos' is the supreme controller for the integrity of the entire set of RBOs.

Related to S5, the algedonic channel[11] has an important function in cases of crisis. This channel is to alert the metasystem, namely S5, about any incident that arises in a primary unit, indicating an incipient instability. In principle, it should reach from S1 directly to S5. However, such a channel cannot be identified in the Formoso RBO.

Reflection: From Diagnosis to (Re)Design

The extensive gaps and deficits in the five preconditions, -clearly defined primary units (S0-S1), mechanisms for coordination and conflict resolution (S2), a functioning metasystem for monitoring, control, and resource allocation (S3 and S3*), strategic capacity to adapt and respond to environmental complexity (S4), and a normative structure that maintains identity, and legitimacy (S5) -, have jeopardised the viability of the system-in-focus. To address the identified challenges and enhance the management system that reconciles environmental, operational, and managerial demands - particularly in economically significant areas such as intensive agriculture - calls for a comprehensive redesign of the governance system.

Several strategic actions are imperative. Table 3, outlines the diagnostic points and proposed design strategies and measures, serving as an initial proposal by the authors. In practice, both diagnosis and design require greater stakeholder participation than previously, to maximise knowledge and promote acceptance.

Operative management and coordination

The process essential for reconciling water demand and availability propels the system-in-focus toward its objective: effective governance of water provision in the Tocantins-Araguaia Region as a whole. Equalize the variety between water use demands and the limits of each catchment by implementing regulation mechanisms for water allocation that not only monitor water withdrawal but also the allowed cultivation area, prioritizing low-impact production and ensuring a fair price for water use.

The fees established for water withdrawal and discharge are insufficient to cover the infrastructure costs required for implementing a proper charging system. Revising the outdated values set in 2015 is crucial. Additionally, the

[10] The concept is directly related to other components of cybernetics, such as the concept of viable systems with their recursive nature, the availability of real-time information, and potential command redundancy. All these factors are connected with the goal of achieving systemic control of the organization, which, among other aspects, involves having decision and action points located as close as possible to the sources of information (decision) and where intervention is needed (action). (Pérez Ríos 2012)

[11] The 'algedonic channel', a concept from Stafford Beer's Viable System Model (VSM), refers to the feedback mechanism that communicates incipient instabilities inside the operative unit to the metasystem. It is crucial for early detection of crises, allowing timely corrective actions and strategic adjustments. This channel enhances the organization's resilience and adaptiveness.

Table 3 Summary of the Diagnostic Points and Proposed Design Strategies and Measures for the Formoso River Basin Organization

Sub-Systems	Diagnostic Points	Design Proposal
S0 ↔ S1 (Primary Units) and the channel Environment	The absence of a River Basin Agency (AgB) in primary units weakens the regulatory capacity of the Formoso RBO. The AgB is essential for local management and implementing the strategic and normative measures set by higher management levels.	In alignment with the Tocantins State Water Resources Plan (PERH-TO), establish a River Basin Agency (AgB) to support the Strategic Management Areas (AEG). This agency would be tasked with providing local management, addressing the regulatory gaps in primary units. The AgB would facilitate consistent enforcement of water use policies, enhance adaptive resource management, and advance PERH-TO's goals for tailored water management within the Tocantins-Araguaia region. However, for the creation of the AgB it is legally required to initiate the collection of water usage fees.
S2 (Coordination), and the channels S1 ↔ S2 ↔ S3 ↔ S3*	The primary dysfunction lies in the fragmented coordination and lack of integration between key information systems (SIGAM, REGLA, CNARH), which hinders efficient decision-making and impairs the effective management of water resources. The operational management system is far too weak to lead and coordinate the primary units.	Develop an AI-driven middleware to analyze, normalize, and correct real-time data, offering predictive insights for strategic adjustments. Create an integrated platform that facilitates data sharing and collaboration across governance levels, enabling real-time, data-driven decision-making for effective management of the Formoso RBO. Strengthen the operational management system by establishing clear leadership structures, defining roles and responsibilities, and implementing coordination mechanisms to align primary units.
S3 (Executive Management), and channel S1 ↔ S3	The lack of financial autonomy, low representativeness, and weak regulatory capacity hinder the CBHRF's ability to enforce decisions, manage conflicts, and ensure effective implementation of the Formoso River Basin Plan. CBHRF does not have sufficient strength to generate cohesion or trigger the necessary synergies.	Enhance the discretion of the CBHRF. Strengthen representation within the CBHRF by creating structured participation channels, ensuring broader input into decision-making processes. Develop a capacity-building program to improve regulatory processes, empowering the CBHRF to enforce water management policies and resolve conflicts. Empower CBHRF by enhancing its decision-making authority, fostering collaboration across primary units, and implementing mechanisms to enhance stakeholder cohesion and synergy.
S3*(Auditing/Monitoring channel)	Limited capacity to fulfill its monitoring and auditing responsibilities due to an overwhelming scope of duties, a lack of compliance among permit holders, insufficient infrastructure, and poor information flow within water management systems, all of which weaken its supervisory effectiveness.	Create a focused monitoring and auditing unit within the CBHRF, implement automated compliance tracking, upgrade infrastructure with data tools and sensors, and enhance information-sharing platforms for efficient decision-making and supervision.
S4 (Policy and Ethos), and the channels Environment↔S4, S3 ↔ 4	Lack of critical discussion limits the effectiveness of water governance decisions; excessive bureaucracy hinders efficient resource acquisition and service contracting; underutilization of the Strategy Room restricts real-time data analysis and decision-making; and insufficient stakeholder engagement impedes the integration of data-driven approaches into operational procedures. A strategic process involving both CBHRF and Semarh is missing. Semarh does not assess the implemented strategies. In other words, Semarh lacks indicators to measure the objectives of the Formoso River Basin Plan, leaving it unaware of its impacts on CBHRF.	Establish a strategic process within the metasystem, primarily between CBHRF and Semarh. Model the organization and its environment. Manage the long-term development of the organization in alignment with the broader external environment. Streamline bureaucratic processes for quicker resource allocation, fully utilize the Strategy Room for real-time decision-making, and establish platforms for enhanced stakeholder engagement and data integration. Develop a strategic framework integrating both CBHRF and Semarh, with clear indicators to assess the outcomes of the Formoso River Basin Plan. Establish a feedback loop to ensure Semarh can monitor and evaluate the impacts of implemented strategies, enabling informed adjustments to support CBHRF's objectives.

Table 3 (continued)

Sub-Systems	Diagnostic Points	Design Proposal
S5 (Normative Management), and the relationship of systems (S3 ↔ S4) ↔ S5	The CERH's role often resembles that of a mere "registration chamber," with insufficient discussion of the water scarcity crisis from 2016 to 2024; a lack of awareness regarding CERH's functions and competencies as the ultimate authority for conflict resolution; and the absence of clearly defined values, norms, and codes of conduct that should guide the organization.	Clarify and strengthen CERH's role by defining its functions and competencies, ensuring it actively addresses water scarcity issues. Establish clear values, norms, and codes of conduct to guide its operations and enhance its authority in conflict resolution. Balance present and future, as well as internal and external perspectives.
Algedonic Channel:	The Algedonic Channel is missing. The non-existence of an effective algedonic channel to alert CERH about incidents in primary units, indicating a failure in addressing emerging instabilities.	The channel would provide direct access to S5. The most immediate link is indicated, e.g. direct access to the key person(s), hotline or phone in general. Mobile and web-based notifications to enhance responsiveness and coordination across all governance levels should be part of the system. Emergency procedures and recommendations for immediate action should also be available, ensuring that CERH is always prepared and able to act promptly to address instabilities.

centralization of profits alongside the socialization of damages necessitates that CBHRF adopt restrictive measures and enhance its monitoring capabilities. These policies should directly regulate the expansion of new cultivation areas to prevent predatory practices and promote sustainable resource use.

Communication channels must be strengthened between primary units (S1) and coordination (S2) to ensure that relevant information about consumption and the state of water resources is always accessible and up to date. Ineffective information systems should be replaced by interconnected data networks that transmit real-time information between local units and coordination, facilitating informed and synchronized decision-making.

CBHRF (S3) must ensure that the variety of operations is proportional to water demands and capacities. This requires an integrated management mechanism where data on consumption and the ecological impacts of operations flow between S3 and primary units, generating reports that support real-time decision-making. Poor management of permits and supervision calls for the implementation of decision-support tools and the introduction of additional regulatory barriers, limiting the economic power of large agricultural producers and ensuring that water is allocated fairly and sustainably.

To clearly define the role of regulatory capacity within CBHRF, it would be crucial to establish institutional relations with a River Basin Agency (AgB), to mitigate potential rivalries and conflicts. Water Law No. 9.433/1997 (Brasil, op. cit.) establishes well-defined competencies and responsibilities for both, and they are complementary. The connection between CBHRF-AgB embodies a standard Principal-Agent model, wherein the principal's duties (River Basin Committee - S3) rely on the actions or information provided by the agent (River Basin Agency – regulatory capacity of S1).

Auditing should be rigorous, with transduction[12] processes that ensure information about water consumption is completely clear to CBHRF, enabling management based on accurate data.

Strategic and normative management

The current deficit of strategic management is caused by an imbalance between the short- and long-term perspectives

[12] In information theory, transduction refers to converting raw data into structured, actionable information. In water resource compliance auditing, this process includes data collection from sensors and other sources, formatting the data appropriately, comparing it against water quality and quantity standards, and ultimately generating reports. Each step translates the data flow into a format that aids decision-making, enabling faster and more precise actions to ensure regulatory compliance.

(CBHRF and Semarh). A more fruitful and robust way to shape the relationship between S3 ↔ S4 is to design, for these two functions, a joint process of debate and reflection, supported by a Strategy Room.

Instead of commanding, the arguments are allowed to unfold. This has the advantage that Semarh is less prone to overlook operational information crucial for executing its strategy or innovations. In this way, the role of CERH in the organization should be to indirectly monitor and guide the discussion between CBHRF and Semarh.

The approach of CERH could help find a solution that better processes the variety exchanged between CBHRF and Semarh. This would boost the effectiveness of the S3 ↔ S4 homeostat[13].

The capacity of Semarh must match that of CBHRF, enabling continuous adaptation and ultimately evolution. Tasks such as modeling, trend and risk analysis, scenario studies, as well as experiments, belong to its domain. Semarh should also propose policies that restrict the use of water resources based on future environmental conditions, such as soil sustainability and water capacity.

Efforts should be made to organize training sessions and workshops to familiarize users with the technology and data available in the Strategy Room. This would empower CBHRF and CERH to leverage the tools effectively, ensuring that the room becomes an integral part of strategic management and operational supervision.

CERH should act as a guardian of residual variety, ensuring that the governance system not only maintains the current balance but is also prepared for future variations that may destabilize the system. CERH must implement a policy that encompasses equity in water use, prioritizing viability. The development of a governance identity focused on sustainability and social responsibility should be a core value, defining standards that guide decisions at all levels of recursion.

The absence of a functional algedonic channel for crises should be addressed by creating a water crisis alert system. This channel must be robust, responding immediately to incipient instabilities such as critical variations in water use, signaling directly to CERH (S5) and, when necessary, to CBHRF (S3), the coordination system (S2), and Semarh (S4).

A key issue is how to make CERH and CBHRF more influential and ensure better, more effective representation of all stakeholders involved. The crucial aspect is the implementation of decisions in practice. It would be worthwhile to review the mission, values, and competencies to reaffirm the roles of organizational actors in the multi-level governance of Formoso RBO. This can lead to a higher level of awareness regarding responsibilities, limitations, and the capacity to implement the IWRM's framework.

In this regard, it would be desirable and probably wise to emphasize the development of institutional capacity of IWRM, reaffirming its plans, priorities, and primarily raising awareness at the political level.

Layout for an Integrative System of Water Governance

The previous section, presented a critical analysis of the existing governance structure based on the VSM diagnosis. It identified systemic shortcomings and proposed key (re-) design strategies for each subsystem to restore viability. This reflection stage was essential to translate diagnostic insights into actionable ideas that address specific gaps in coordination, strategy, operational management, and regulation.

Building on that reflection, this final section consolidates those proposals into a synthesized, systemic framework. It introduces a conceptual model for the Formoso RBO grounded in Variety Engineering[14] that visually and structurally organizes the (re-)designed system governance.

While the prior section focused on outlining what needs to change and why, this layout brings the varieties into balance in each pair of mutually governing systems ('homeostats'). Figure 5 provides a generic diagram that is sufficiently abstract to enable the condensed version of the multiple details developed up to this point.

Operations

Operations must align water availability with demand. Both amplification and attenuation of variety are needed for this purpose. Attenuation of the environmental variety is achieved through the standardization of registration and water use rights allocation procedures. Amplification of their operational variety is realized by implementing adaptive management practices, such as flexible allocation frameworks, real-time monitoring systems, and scenario planning. These practices enable the system-in-focus to respond effectively to oscillations in water demand and environmental conditions, ensuring a more resilient and adaptable approach to resource governance.

[13] In this context, a system of mutually adaptive agents or systems procuring a state of equilibrium ('homeostasis').

[14] The term coined for the concerted amplification and attenuation of varieties is 'Variety Engineering' (Beer 1979). Variety Engineering stands for the combinations of amplification and attenuation used to bring a system of interactions into balance. Amplification and attenuation are the actions or strategies by which the environmental or operational varieties of a set or agent are changed (Schwaninger and Ott 2023:2, Alves 2025).

Management metasystem

The management metasystem amplifies its operational variety to regulate and develop the primary units. Conversely, it attenuates the variety of the primary units to enable joint discourse and action by implementing the functions of a River Basin Agency (ABg).

Coordination

Coordination's primary task is to attenuate variety by damping oscillations between the primary units and filtering information from these. In turn, coordination amplifies its variety in serving the primary units. The issue of interoperability between SIGAM and REGLA must receive particular attention, as it directly impacts the viability of the system-in-focus. Higher levels of recursion must prioritize this challenge to ensure seamless integration and functionality across platforms.

Environment

The environment must be gauged regarding its potential variety, both present and future. Which trends will increase the complexity of the environment? A complexity perspective suggests that multiple factors will likely be important and interrelated: new fluctuations in the environment (e.g., ecological, social, and economic crises), growing needs and demands, fragmentation of stakeholder groups, new claimant groups, and shifts in power relations. Understanding these trends is crucial for effective Variety Engineering.

This proposal allows managers to focus on the viability and sustainability of the Formoso RBO. It provides the framework to distinguish between functional and dysfunctional structures and behaviors. Variety Engineering should enable the planned concept of Integrative Water Resources Management (IWRM) to become a reality in the Formoso RBO.

Finally, the governance and management of an RBO involve reconciling diverse interests, such as those of farmers, local communities, and other stakeholders, at the organizational boundary. Herein lies the ultimate challenge for requisite variety.

Conclusion

Let us return to our main proposition formulated at the outset, which states that the governance of RBOs can be significantly improved by applying a cybernetic organizational framework as introduced in this study. Based on this, we can conclude that the theory of the VSM asserts that it offers the necessary and sufficient preconditions for the viability of any social system. If this theory holds, then the diagnosis carried out and the design proposed here should lead to significant improvements in the governance of the Formoso RBO.

We return now to our research question: we asked what a cybernetic perspective can teach us about the organization and governance of RBOs, and how it may support improvements toward viability.

The features, functionalities, and dysfunctions identified in the diagnosis directly informed a design proposal. This research has the potential to improve water governance precisely because it is grounded in a robust theory. It offers practical insights for policymakers and managers working in river basin contexts, particularly those seeking to manage complexity and enhance institutional adaptability.

The proposed design is functional and structural in nature. It includes strategies for involving local communities in decision-making, encouraging cooperation among stakeholders, and using data-driven approaches to inform policies. In essence, this research moves beyond managerial efficiency: by applying the recursive logic of the VSM, it contributes to a broader understanding of autonomy, coordination, and systemic responsiveness in water governance.

The application of the VSM to the Formoso RBO has yielded a deeper understanding of the governance problem because it made visible the system's structural deficiencies, such as missing channels of coordination, overloaded subsystems, and absent feedback loops—that are often neglected in conventional organizational assessments. By diagnosing the systemic causes of dysfunction, the VSM enabled a more coherent and integrative response to governance challenges.

Theoretical claims about the universal applicability of the VSM to social systems are strengthened by this case. Regardless of scale or context, any RBO can, in principle, be modeled using the VSM. When applied competently, the model offers similar benefits in terms of identifying structural flaws and supporting institutional (re)design.

However, the limitations are evident:

- First, application alone does not guarantee success. A professional, theory-driven use of the model is the crucial precondition for improvement.
- Second, empirical validation of our initial proposal is possible only in hindsight - that is, once the proposal has been implemented in practice.

In this case study, the VSM proved to be a powerful diagnostic and design tool. The literature supports its suitability for governance improvement, and stakeholder interviews confirmed the relevance and value of the intervention. Notably, the diagnosis contributed to several concrete outcomes: it prompted a revision of water use charges to better reflect actual demands and resource distribution; it exposed the absence of data interoperability across systems

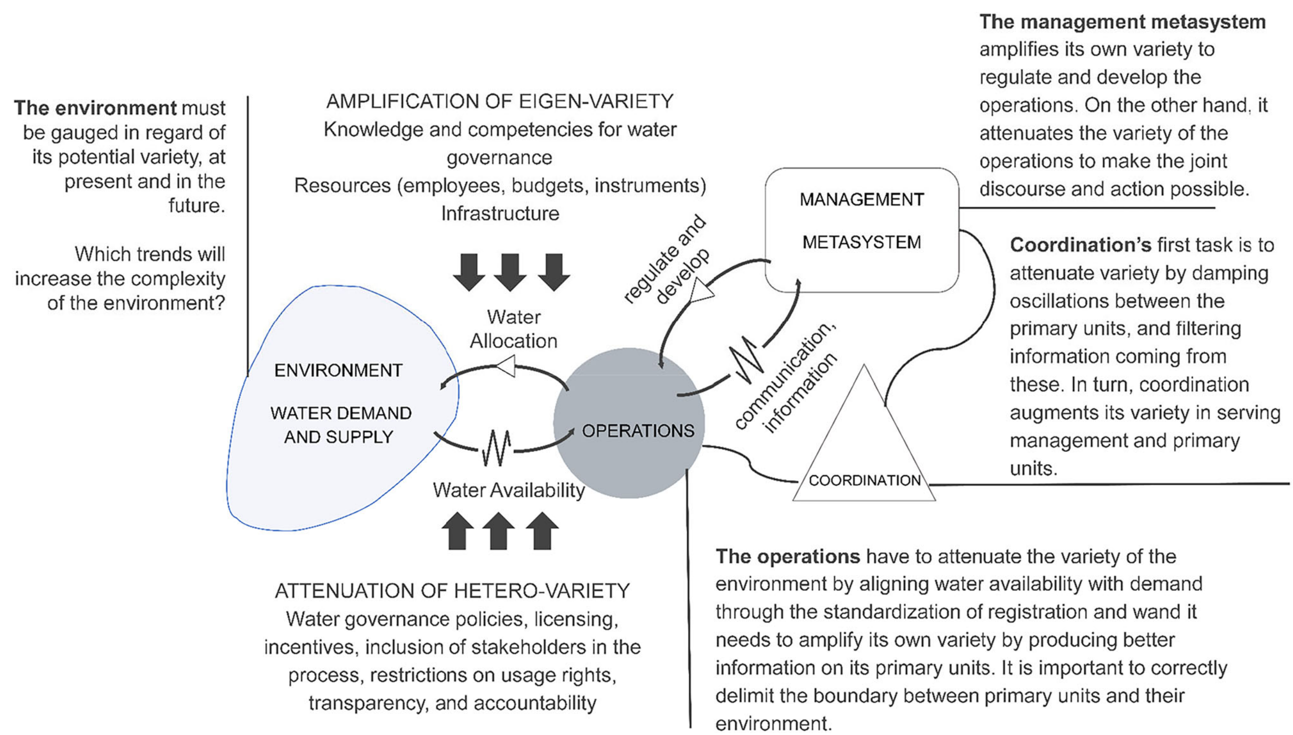

Fig. 5 From diagnosis to (re) design Formoso RBO. Source: Adapted and modified from Lassl (2019c)

and revealed critical information gaps across the river basin, resulting in fragmented "islands of information." These insights, made visible through the systemic mapping enabled by the VSM, have already informed institutional responses. As a result, the State Water Resources Council (CERH) began to guide discussions around resource allocation plans and accountability procedures with increased transparency and coherence. Many respondents expressed the view that the work should continue and expand. A follow-up project is already underway, integrating managerial and technological strategies with participatory methods for diagnosis and design.

Finally, as we look to the future, it is important to reassess the role of water beyond its material properties and managerial issues. Building on Rifkin (2024), we suggest that prevailing views of water as a commodity must evolve taking into consideration the integrity of the hydrosphere and its systemic interrelations. A paradigm shift is needed. Rather than being treated merely as an economic asset, water needs to be understood as a foundational element that sustains life and enables the functioning of multiple interconnected biophysical systems—alongside other essential components such as air, soil, and biodiversity.

Data availability

No datasets were generated or analysed during the current study.

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Compliance with Ethical Standards

Conflict of interest The authors declare no competing interests.

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